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Method for the Rapid Replacement of the Travis Spur Rail Bridge over I-278 Highway

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Abstract: Rise in traffic volumes of urban highways over the last decades has led to an increasing need for widening both highways and access roads. The present case study deals with the replacement of the Travis Spur Rail Bridge to allow for larger width of roadways that lead to and away from the New Goethals Bridge, which connects Elizabeth, New Jersey, to Staten Island, New York, in the United States. The main objective of the project was to apply a rapid method for the replacement of the existing bridge, which was performed during the Columbus Day weekend (7-9 October 2017). Considerations of all existing constraints, which include high traffic volumes and limited space for material laydown and equipment positioning, are presented first. To respond to these challenges careful planning of the construction steps of the substructure (cap beams supported on circular piers) and the superstructure of the bridge (two-span steel deck) had to be carried out both temporally and spatially before the replacement weekend, which is described in the second part of the paper. The final part presents the different phases of the demolition / replacement process to minimize traffic disruption.

Keywords: Rapid Bridge Replacement, Steel Deck Erection, Bridge Demolition, Traffic Diversion Plan

1. Introduction

Widening of modern highways within metropolitan areas involves a significant set of challenges both spatially and temporally that should be addressed appropriately by the engineering teams. Rapid replacement of bridges is a subject that has attracted significant attention over the last decades both from the standpoint of researchers and constructors in engineering [1, 2]. Moreover, new techniques for accelerated bridge construction have permitted minimization of construction duration [3-5]. This is due to the fact that bridges and the associated highway and/or railway network are considered essential lifelines for urban areas during natural or man-made catastrophes and therefore access limitation to them should be kept at minimal levels [6-8].

The Travis Spur Rail (TSR) Bridge receives railway traffic and is situated over the I-278 Highway that leads to the Goethals Bridge, which in turn connects Elizabeth, New Jersey, to Staten Island, New York. As the New Goethals Bridge needed to accommodate more traffic lanes than the old one, its deck as well as the access roads had to get wider. To arrange such road widening, the old five-span TSR Bridge had to be replaced by a new two-span bridge. The site included several limitations with regard to space arrangement and planning schedule. In response to these technical challenges, the engineering teams worked with commitment to provide a construction method that ensures safety, efficiency, and productivity.

The objective of this paper is to describe the works performed to demolish the old bridge and erect the new one with main emphasis on several specific features of the construction process necessary to meet the requirements of this specific project. First, the project constraints are briefly presented. Then, the undertaken works for the construction of the substructure and the superstructure of the new bridge are described, as well as the work sequence for the rapid replacement of the existing bridge over the time span of one weekend.

2. Problem definition and Project Constraints

To accommodate higher traffic volumes, the New Goethals Bridge is two times wider than the existing one. However, the concrete piers of the existing TSR Bridge would constrain the width of the access roads to and from the New Goethals Bridge. Therefore, the goal of the TSR Bridge replacement project was the removal of both the existing substructure and superstructure and the replacement with an entirely new structure that would allow the desired road widening, as shown in Figure 1. For the accomplishment of the first objective, the demolition of five existing steel spans (2 main spans), four concrete piers and two concrete abutments was required, while for the second one, ten drilled shafts, a new abutment and two piers, three new cap beams and two steel spans were constructed. Since the main objective of the replacement was not the structural or seismic upgrade of the existing structure, the materials and bridge structural system were not modified. The new bridge, however, has slightly longer spans compared to the existing one and is designed according to current standards.

Figure 1. *New Travis Spur Rail Bridge after the replacement weekend.*

Access to the work site at the Travis Spur had its own set of challenges. The rail bridge spanned across I-278 eastbound and westbound directions with high volumes of traffic and very little room for material laydown and equipment positioning. Furthermore, the equipment for the excavations had to be selected judiciously so as to avoid damage of the asphalt and the existing road.

With regard to time constraints, the bridge replacement had to be accomplished within 100 hour track outage. Within this time frame, a full Goethals Bridge closure was given for a duration of 10 hours, in order to complete the demolition process. After the full bridge closure, traffic had to be diverted around the work site, so that normal traffic could be maintained.

Construction of the components of the substructure and the superstructure simultaneously and prior to the replacement process consisted the only viable way for time efficiency. Since the required connection between piers and deck was through bearings rather than monolithic, the works related to superstructure and substructure construction were performed independently. The following sections describe the critical decisions of the engineering teams as well as the works performed on the substructure and the superstructure components to meet the project requirements and constraints.

3. Substructure

Since the time needed for concrete hardening overpasses by far the allocated time of track outage, the main objective of the engineering teams was to construct all substructure components prior to the demolition / replacement weekend. The need for high compressive strength of the substructure members rendered inevitable the use of reinforced concrete, as was the case for the existing substructure as well. These choices had significant implications on several technical aspects of the project. The new RC piers and their foundation should not interfere with the respective members of the existing bridge. Moreover, the cap beams must be fabricated in advance but positioned with precision on top of the new piers after the demolition of the existing piers during the replacement weekend. To achieve the aforementioned goals, the substructure of the new bridge consisted of drilled shafts, piers, cap beams and pedestals. In total, ten drilled shafts measuring 1.83 m (6 ft) in diameter were socketed into rock. Six of the shafts received piers of 1.68 m (5.5 ft) diameter. On top of each pier pair, a new cap beam was installed, which supported the steel superstructure, which will be described later on. Only the north abutment cap beam included a backwall, which varied in height. The dimensions of abutments, piers and cap beams are shown in tabulated form in Table 1. All cap beams had a 4% wash on the top and pedestals for the bearings.

Table 1. *Geometric properties of the new bridge substructure members.*

Geometric property	North Abutment	North Pier	South Pier
Pier/Abutment Diameter (m)	1.68 (x 2)	1.68 (x 2)	1.68 m (x 2)
Pier/Abutment Height (m)	4.41	4.51	3.40
Cap beam Length (m)	10.36	12.04	12.19
Cap beam Width (m)	2.67	2.13	2.13
Cap beam Height (m)	1.52	1.52	1.52

3.1. Drilled Shafts

After examination of various alternatives for the foundation system of the new RC piers, the engineering teams opted for the solution of drilled shafts rather than massive footings, as the shaft footprint is rather small, while reuse of the existing foundation members [9] was not possible. This choice minimizes the disturbance to the existing members that are in proximity. On the same time, drilling is a much faster process compared to works associated with excavation, provisional soil retaining and footing formwork. After the completion of excavation works at both north and south abutments, the drilled shaft construction commenced. In total, ten shafts were drilled for the new rail bridge, each measuring 1.83 m (6 ft) in diameter. With regard to the casing geometry, a wall thickness of 19 mm (¾”) and length varying from 10.36 m (34 ft) to 12.80 m (42 ft) were selected. Cutting teeth were welded on the casing bottom and a 0.3 m (1 ft) driving band of 19 mm (¾”) thickness was positioned around the top of each casing (Figure 2). When the equipment was brought to the field, 2 holes were cut in the casing top in order to fit a shackle. In addition four twister slots were cut around the top of the casing. A device was fabricated and attached to the drill rig to guarantee that all four twister slots would work together during the drilling process and to ensure that no shearing would occur under the applied load.

Figure 2. *Teeth welded on casing.*

All ten shafts were installed by the LB-36 drill rig shown in Figure 3. The crane had to move at off-peak traffic times in order the traffic flow to be maintained on I-278. In order to provide access for the drill rig, the existing wing walls had to be demolished, adding extra time and cost to the operation. The shafts of the north pier were positioned first (median strip of I-278 - Figure 3b). The LB-36 drill rig and an 895 crane were used for this operation during a graveyard shift. The casing was relocated by the drill and the twister slots were engaged. The casing was then spun into the ground at the correct location (Figure 4).

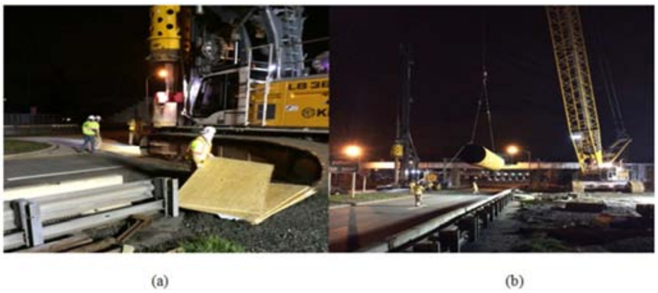

Figure 3. *(a) Mobilizing the drill to median and (b) Casing transportation over I-278 WB to the median strip).*

Figure 4. *Aligning twister attachment into slots.*

During the drilling process, the excavating bucket was used to remove the soil from the casing, leaving approximately 1.52 m (5 ft) of soil at the bottom as a plug until contact between casing and rock was achieved. The casing was then flooded with water and the remaining soil was removed. Drilling of the rock was relatively easy and a combination of excavating bucket and core barrel were used to drill the 1.68 m (5.5 ft) diameter rock socket. Each rock socket had a minimum depth of 2 times the diameter. For the TSR Bridge shafts, air lifting was not possible because of large distance from a water treatment plant and the possibility of a pipe failure over live traffic. It was decided to use the cleanout bucket and weld a plate on the bottom to assist the collection of fine material from the shaft bottom. To get acceptance of the shaft (i.e. that the shaft bottom was sufficiently clean to pour concrete), a Shaft Inspection Device (SID) [10, 11] test was performed.

After the SID was removed, the casing was cut to the definite elevation according to the plans. Once the shaft passed the SID test, the 895 crane would pick and transport the rebar cage and set it into the casing (Figure 5). The shaft rebar included the rebars of pier to be cast above. The same crane was also used to assemble the tremie pipe and hopper and the tremie mix was pumped by a pump truck provided by Precision Concrete Pumping until concrete of good quality was overflowing the casing top (Figure 5). As the tremie was placed, a 10.2 cm (4”) hydraulic pump was used to pump the water off the top of the shaft back to the water treatment plant. During some of the placements, the pumps malfunctioned making dewatering difficult, which resulted in some additional laitance on the shafts. Cross-hole Sonic

Logging (CSL) tests [12] were conducted and three days after shaft placement, the concrete quality was verified. Once the results were approved, the CSL tubes were grouted and the laitance was chipped from the top of the shafts.

Figure 5. *Transportation of the rebar cage with picking ring (left) and placing tremie with pump truck (right).*

3.2. Piers

The new bridge was supported on 6 piers, measuring 1.68 m (5.5 ft) in diameter in order to fit to the drilled shaft diameter (see Section above). This choice resulted in rebar installation during the shaft operations (Figure 6), the remaining work for the piers being the touch up of the epoxy paint coating and the installation of a plywood shoe and EFCO type formworks [13] (Figure 7).

Figure 6. *Rebar on top of the shaft.*

Figure 7. *Formwork set around the rebar cage.*

The twin piers at the north abutment were placed using the 40 ton crane, while the remaining 4 piers were placed in sets of two using the 322 excavator and concrete bucket aced. The formworks were wrapped in concrete blankets prior to concreting and thermal sensors were set in the middle to monitor the cure period (Figure 8). It must be noted that due to the schedule and sequence of work, 6 formworks were brought to the site from EFCO [13], so that works would proceed simultaneously for all piers. Once the thermal cure period (7 days) passed, the formworks were removed. The work following the formwork removal was the joint preparation on top of the piers. This included bush hammering of the pier top in order to expose the aggregates and clean off any loose concrete. The exposed part of the rebar cage was again touched up with epoxy (Figure 8) and the exact center of each bar was surveyed.

Figure 8. *Wrapped forms for concrete thermal control (left) and completed pier (right).*

3.3. Cap Beams

Concurrently with the pier works, the construction of the 3 cap beams of different dimensions commenced near the side of future installation. The specificity of these works was related to the need of monolithic cap beam-pier connection after construction of both components. To achieve this goal, 18 vertical rebars were protruding from the concrete mass of each pier. To achieve perfect connection, the cap beams would receive 36 grouted couplers in the bottom, where the 36 protruding pier rebars would be fixed. Tight space tolerances regarding the difference between the rebar diameter and the coupler opening had to be respected. The cap beam form was a standard EFCO system and was built on top of 3 concrete supports to facilitate rebar coupler inspection and cleaning (Figure 9). The space between coupler and rebar was filled with hard polymer to achieve rebar centering into the coupler. Once the couplers were positioned on the rebars sticking out of the piers, a mini-cage rite was used as a template (Figure 10), allowing everything to be locked together. The couplers were tied to the cage rite and rebar hoops were installed around the exterior of the couplers to increase the stiffness (Figure 10). Banding of the couplers offered additional security. Once full assembling was achieved, the template and couplers were removed from the pier and placed on the steel form. After the templates were set in place, the pin setters were tightened and the couplers were locked into position. Each coupler had two ports, for the grout inflow and outflow, the latter one receiving a PVC sleeve which was extended through the forms. In addition to the grouted couplers, anchor bolt sleeves were used for the future cap beam bearings.

Figure 9. *Soffit set on 3 supports.*

Figure 10. *Rebar hoops placed around the couplers.*

To support the rebar cage load on the elevated soffit in the temporary location, 3 posts were installed along the unbraced side of the form. Half of the soffit was supported on the long steel form spanning the entire cap length, while the other half was supported on these posts. Since positioning of the long horizontal bars on the formwork bottom was obstructed by the template (Figure 11), the couplers were dismantled and the cage rite was cut so that rebar and stirrups could be accurately placed. After tying together the reinforcement cage the forms were closed up and a walkway was installed around the top to provide access for pedestal work and casting (Figure 12).

Figure 11. *Tied on soffit rebar.*

A total of 8 steel pedestals were placed as well. The pedestal formwork consisted of plywood spanning along the short side of the cap to provide a hung form. The anchor bolt sleeves were made of 10.2 cm (4”) corrugated plastic pipe with a 19 mm (3/4”) plastic tube attached to the bottom so that grout for the bolts could be placed after bearing installation (during the replacement weekend). Additional sleeves were added at each pier location, to allow for easy grouting of the 25.4 mm (1”) vertical gap between the cap beam and the pier. Each pier location received 4 38.1 mm (1.5”) sleeves to make sure the entire area would be covered with grout. To control the concrete placement, a pump truck was used (Figure 13). The location of each PVC sleeve was marked, allowing the constructors to track the exact sleeve locations and prevent sleeve-vibrator contact resulting in sleeve damage. Verticality during pouring was guaranteed by a rebar passing through each sleeve. Once the cap beam was casted, a 4% wash was finished on the top. The smaller pedestals (76.2 mm or less) were constructed monolithically during grout pouring, while the larger ones were poured the following day.

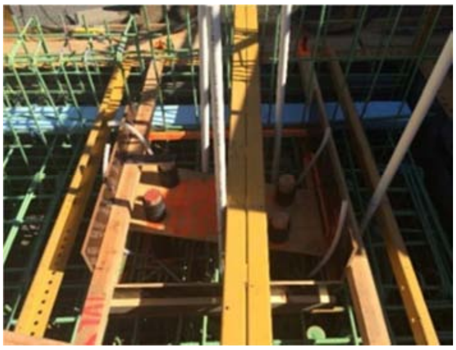

Figure 12. *Pedestal forms with anchor bolt sleeves.*

Figure 13. *Casting of the cap beam using a pump truck.*

As soon as the concrete placement on each cap beam was completed, a retarder was added to the surface of the future pedestal, which allowed the use of power wash for the completion of the joint preparation instead of bush hammering, a method which was also used on the north abutment backwall.

4. Superstructure

The bridge superstructure included bearings, two steel spans, concrete approach slab and miscellaneous tie-in steel. Eight new bearings and two existing bearings were used in combination with steel bolsters to achieve the correct elevation. The new steel spans consisted of girders, floor beams, deck plates, curb plates, side plates, and knee braces. Information on the spans properties is given in Table 2. To reach the same elevation with the existing rails before and after the bridge replacement, it was decided to perform all rail work (ballast replacement, ties, and rail positioning as well as the installation of a new guardrail system) once the superstructure would reach its definite position.

Table 2. *Properties of the new bridge spans.*

Span	Length (m)	Mass (ton)
1	29.11	198
2	35.51	238.5

The most challenging part of the superstructure was the construction of the two steel spans, due to the high volume with regard to other members and the limited space that was available in the TSR Bridge proximity. In order for the steel superstructure construction site to be adequate, ground leveling was performed through Dense Grade Aggregate (DGA) spreading with a dozer and compaction using a roller. The shoring for the new steel spans consisted of 2 connex boxes on each span end, and grillage beams bolted onto them to distribute the load to the connex corners (Figure 14a). Inside each connex box, three concrete deadmen were placed in order to counterbalance the weight of the first girder. In order to set the steel in the same way it was previously assembled at the shop, shoring towers between the connex boxes had to be installed. Two rows of crane mats were placed to distribute the load on the shoring towers; one for the girder and one for the floor panels. The shoring towers had grillage steel on top as well to transfer the load into the legs of the towers.

The length of girders used for span 2 was equal to 36.58 m (120 ft) and their weight was 667 kN (150 kips). To cross the existing Goethals Bridge, the traffic in the bridge area was suspended at 4:30 am. The trucks transporting the girders first travelled over the westbound lanes of the existing Goethals Bridge, then were directed into Gulf Avenue just before the toll plaza, and finally each girder backed down Gulf Avenue until arriving in front of the 895 crane at the proper distance for the pick and set process. The girders length was 28.96 m (95 ft) for span 1 and weighed 467 kN (105 kips). The process was the same for their transportation, except the fact that they exited I-278 on the Goethals Road North side at the Port Authority access ramp prior to the toll plaza.

Placing the girders onto the shoring involved its own set of space challenges since the tail end of the beam had to swing out over the highway as the crane swung into position. For this reason, setting of the girders was planned to take place during the morning following the transportation in the same time frame (4:30 to 5:00). The Port Authority police provided assistance in shutting down the bridge for all required closures. Once the girder was positioned on the grillage steel, traffic circulation was again allowed and the ironworkers secured the girder in the new temporary position. The pick plan called for the 895 crane to have 37.49 m (123 ft) of boom and 5 parts of line. The rigging consisted of two 15.24 m (50 ft) 6.35 mm (1/4”) wire rope slings attached to a picking beam with 80 tones capacity (Figure 14b). From the picking beam, there were two 3.05 m (10 ft) ENR 13 round slings to a Crosby beam clamp. Then, the ironworkers raised the shoring towers to fit them tightly underneath the girder.


(a) (b)

Figure 14. *(a) Grillage steel positioning on connex box, and (b) setting of the first girder for span 2.*

After the first girder was positioned and secured, the deck panels were set and fastened to the girder. Each deck panel consisted of 4 floor beams running perpendicular to the span length and a welded deck plate. Each floor beam was bolted to the girder’s stiffener. To minimize the risk of fall during installation, a lifeline was placed along the girder’s top so that the crew members could tie off during the operation. During the positioning process, the beams had to be shimmed to the shoring towers in order to keep the camber and allow the bolts to fit up. In order to release the initial girder bracing, 4 floor beams had to be 100% bolted (2 on either side of the centerline of the girder). After the girder bracing removal, the second girder was set in a similar manner to the first one, with only exception the fact the second girder had to be fixed to each floor beam prior to setting down (Figure 15a).

Once both girders and all the floor beams were set and bolted, the knee braces were placed (Figure 15b). The knee brace spacing corresponded to the distance between four floor beams and was connected to the girder and deck panels using bolts that were fixed tightly and inspected. Afterwards, the side and curb plates were installed in the same way. Prior to their rigid fixation to the existing structure, the shoring below the new span was removed in order to facilitate the access to the workers for bolting up.


(a) (b)

Figure 15. *(a) Floor beams before receiving second girder, and (b) view of span 2 with all knee braces installed.*

For time saving reasons waterproofing and painting were applied at the end of the erection process. The waterproofing was performed over the span of 2 weeks through sandblasting of the deck and side plates in order to achieve

SSPC-SP 10. Then, a primer coat was applied to all blasted surfaces (Figure 16a). Afterwards, a cold “Eliminator” waterproofing membrane was applied twice to get the desired thickness (Figure 16b). The procedure schedule was dictated by the steel temperature and was often performed during early evening. Finally, the touch up painting of the bolted connections and any scratches occurred during installation was accomplished over approximately one month.

Figure 16. *Waterproofing works on top of span 2: (a) primer coat, and (b) finish coat.*

Once the different components of the bridge substructure and superstructure were erected, a rapid replacement process had to be set up. The two main objectives of this process included the demolition of the existing bridge (substructure and superstructure) and the placement of the new superstructure in its definite position. The different phases of this procedure, which involved significant challenges from a managerial point of view, are described in what follows.

5. Rapid Replacement Sequence

The replacement weekend at the Travis Spur consisted in demolishing 5 existing steel spans and 6 existing concrete abutments/piers, placing 3 new cap beams, and rolling in two new steel spans on Self Propelled Modular Transporter (SPMT) machine to further accelerate the procedure [14]. The situation prior to the work is shown in Figure 17a. All operations had to be completed within a 100 hour track outage from Thursday at 14:00 to Tuesday at 00:01. Within the track outage, the Port Authority allowed a full closure of Goethals Bridge for 10 hours to demolish the existing TSR Bridge. Following the complete bridge closure, the traffic was diverted around the work site in order to maintain continuous traffic flow. In total, five phases were planned, which are summarized in Table 3 and explained in detail in what follows. A time-lapse video of the demolition can be found in [15].

Table 3. *Main activities schedule over the super weekend at the Travis Spur.*

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Starting time	14:00 Thursday	22:00 Friday	08:00 Saturday	07:00 Sunday	06:00 Monday
Ending time	22:00 Friday	8:00 Saturday	07:00 Sunday	06:00 Monday	12:01 Tuesday
Removal	- Ballast / tracks / ties - Bearings (S)				
Demolition	Sawcut of S pier	- Steel spans - RC piers	- RC piers (median & south)		
Placement	- Cap beam (S) - Bearings (S)		- Cap beams (N) - Bearings (N) - Span 1	- Bearings (N pier & N abutment) - Span 2	- Transition slab - Ballast / tracks / ties - Drainage
Traffic Circulation		Goethals Bridge full closure	EB lanes → Gulf Ave. WB →normal	EB lanes → Gulf Ave. WB →EB lanes	Normal

5.1. Track Outage Beginning (Phase 1)

The first operation of this phase was the south abutment saw cut that was to begin at 14:00 on Thursday but started at 15:15 due to a railroad schedule delay. First the wire saw subcontractor performed one horizontal and two vertical cuts. This method was selected since the south abutment was in close proximity to the shoring towers and the new piers (Figure 17b). Simultaneously, the railroad work subcontractor started removing all material necessary for circulation (tracks, ties, and ballast). When the Gulf Avenue Bridge clearing was completed, hydraulic jacks placed on the shoring towers were loaded to apply pressure and raise the bridge by 12.7 mm (1/2") to remove the existing bearings from the south abutment. These bearings were then taken to the fabrication area, prepared and welded to the bolsters that would eventually be set back on the new cap beam to support the existing Gulf Avenue Bridge.

Figure 17. *(a) Situation prior to super weekend and (b) Wire sawing of south abutment.*

After the removal of tracks, ties and ballast, operations started at the north and south abutment. On the north abutment, the area between the sheet pile bin wall and the south of the cut off sheets was excavated to a level just below the future cap beam. On the south abutment, the area between the bin wall sheets was excavated enough to allow access to the Gulf Avenue Bridge deck. After the demolition completion, the remaining soil was transferred from the area between the sheets to the bottom of the wire saw location, while the sheets and the existing concrete blocks resulting from the wire sawing were removed.

The preparation work consisted in adjustment of pier's top elevation using epoxied steel plates and positioning insulation with the grout coupler washer around each protruding rebar. Then, the south pier cap beam was placed under the existing Gulf Avenue Bridge, leaving little space for adjustments between rebar and couplers of the two piers per axis (Figure 18). After positioning of the cap beam, Masonite board formwork was posed in the gap between cap beam and piers and the grout couplers were grouted using SS Mortar grout. The process for each coupler involved pumping from the bottom port until the grout returned out of the top port, followed by plugging of both ports. The final step of the cap beam placement consisted in grouting the gaps between pier and cap beam using a rapid set grout from the top of the cap beam through use of the 38.1 mm (1.5") PVC sleeves that were previously embedded during the cap beam casting.


(a) (b)

Figure 18. *South pier cap beam placing (a) before and (b) after rebar alignment with pier couplers.*

After the cap beam was placed and grouted, the existing bearings that were previously removed and welded on bolsters were set on the new cap beam. Again, the gap between bolster and cap beam was filled with grout and when a grout strength of 20.7 MPa (3,000 psi) was achieved, the jacks were released and the existing bridge was again supported on the bearings. The same procedure was followed for the north abutment cap beam with only exception being some additional preparation work, including trimming back the cutoff wall sheets that interfered with the future cap beam location as well as concreting the space between sheet bellies and road plates, placed to keep the soil back.

5.2. Goethals Bridge Full Closure (Phase 2)

Phase 2 first consisted in setting up all necessary equipment (signage, barriers, cones, and barrels) to divert traffic away from the Goethals Bridge in both directions, as well as positioning steel plates to protect the roadway during the demolition process.

After all security measures were in place, the demolition started, with 3 excavators with shears demolishing the steel spans, 2 excavators with hammers demolishing the concrete piers (Figure 19), and one excavator with grapple and one loader being used to load out steel material into container trucks that would be directed to the scrap yard. Concrete debris was loaded into dump trucks and directed to the main Goethals Bridge project site for later testing. At the same time, DGA was being transferred from the satellite yard, spread to the I-278 eastbound lanes and then compacted to reach the yard height (range between 0.30 m and 0.91 m) and then gradually sloped down to the elevation of the roadway to create a path for the SPMTs.

Figure 19. *Demolition process: Shearing down the existing TSR Bridge deck (left) and Hammering out the existing abutments (right).*

The demolition process in the I-278 westbound lanes was stopped at 6:30 Saturday to clean up the lanes and allow for normal traffic circulation. With regard to the spatial traffic schedule for the next phase, the Goethals Bridge was opened, westbound lanes were set in the normal configuration while eastbound lanes were diverted to Gulf Avenue and back to I-278 just before the toll plaza.

5.3. Eastbound Traffic Diverted To Gulf Avenue (Phase 3)

After the eastbound traffic was diverted to provide unobstructed access to the south side of the bridge, the demolition of the concrete piers in the median pier and the south abutment was completed. Then, all remaining material was loaded out and when the area was cleared, crane mats were mobilized onto the eastbound lanes to pick and position the cap beam on the north pier in the same way as previously performed on the south pier. Due to cure time limitations prior to loading the cap beam the north cap was not grouted.

In the meanwhile, the access for the SPMT was completed through placement of DGA and road plates to allow for enhanced SPMT weight distribution on the DGA. Then, Bay Crane arrived on site to jack the new span up onto the SPMTs while a loader was used to clear the shoring boxes from the travel path.

Once the bearings were in place and the shoring was removed, the SPMTs brought the span down the ramp and set it on the bearings. The roadway clean up, including DGA and road plate removal, was performed soon after with all material being stockpiled into the median or transferred to Port Ivory for storage until used for the second ramp on the westbound lanes. Meanwhile the SPMTs were transported just before the toll plaza and staged in the median so the next traffic switch stage could take place.

With the eastbound lanes clear once again, westbound traffic was redirected to the eastbound lanes and again to the westbound lanes just prior to the Goethals Bridge for the following phase. Following this traffic switch, all equipment was pulled into the westbound lanes so as to allow unobstructed access to the north side.

5.4. Westbound Traffic Diverted To Eastbound Lanes (Phase 4)

After the traffic switch, the anchor bolt sleeves in the north and south piers were grouted and the four new bearings were set on the north pier and north abutment to support the next span. The welding of the bearings under span 2 was also performed at this stage. The DGA ramp and road plates were then rebuilt on the I-278 westbound lanes in the same way as previously completed on the eastbound lanes. Afterwards, once the new span was fastened tightly, the shoring boxes were removed, and the SPMTs rolled the new span into its final location (Figure 20). Then, the SPMTs staged out of the way and the roadway was cleaned up and restored normal traffic flow in both eastbound and westbound directions.

Figure 20. *Rolling Span 1 on north abutment and north pier cap beams using SPMTs.*

The work sequence described in Sections 5.3 and 5.4 shows that if steel spans with length approximately equal to 35 m are fabricated in the final position vicinity, accurate placement in the definite position, including connection to the substructure, is feasible within 23 hours. Key issue for the success of this work step is the protection of the road surface underneath the span using DGA and road plates.

5.5. Normal Traffic and Track Outage End (Phase 5)

With both steel spans being in place, Monday was dedicated to the connections at the north and south ends as well as the joint in the middle of the two new spans.

The void created by the demolition of the concrete stub at the beginning of the weekend was filled with a rapid setting concrete mix, while in the middle of the two new spans, a new sliding plate was installed, with the north end bolted and the south end equipped with countersunk bolts to slide over. Once concrete gained sufficient strength, a waterproofing membrane was applied from the new steel bridge over the concrete and the existing Gulf Avenue Bridge. Afterwards, the floor drain was installed on the surface of the waterproofing membrane. The final stage included the ballast spreading and ties positioning by the rail work subcontractor.

On the north side connection, a bent plate with studs on its lower side was picked and positioned in the keyway within the backwall (Figure 21a). The plate was shimmed up and the formed gap was then grouted. Afterwards, the form was removed in order to place the precast approach slab (Figure 21b). The slab was then grouted in place and the sliding plate was installed and rotated. Finally, waterproofing, and floor drain was installed.

Figure 21. *(a) Bent plate grouted into the backwall, and (b) Placing the approach slab on the backwall studs.*

After all ballast and ties were set, the remainder of track work was completed by 5:00 and the first train crossed the new bridge at 10:30 Tuesday morning, falling within the planned schedule. This proves that for a 65 m bridge it is feasible to complete all necessary works before receiving rail traffic within 23 hours if waterproofing and painting of the spans is applied beforehand.

6. Conclusions

Rise in traffic volumes during the last several decades has led to significant increase in the frequency of bridge replacement projects. At the same time, government entities are increasingly demanding that public disruption is minimized, since bridge systems and the associated transportation networks represent essential lifelines for human societies. The task of rapid replacement of the Travis Spur Rail (TSR) Bridge, passing over I-278 Highway, which leads to the Goethals Bridge, connecting New Jersey to Staten Island, falls within this category of projects, with significant constraints regarding time, lane closures and traffic flow. This article describes the work of the engineering teams to respond to this unique set of challenges. The conclusions of this case study that are valuable for future bridge replacement projects are as follows:

i. Construction of the substructure of the new bridge prior to demolition and replacement saves significant amount of time, especially when the new piers and abutments do not pose very strict constraints in terms of the available space. For the new TSR Bridge this stage included the construction of ten new drilled shafts, six piers, and three cap beams.
ii. For non-integral bridges, like is the case of the TSR Bridge, fabrication of the superstructure (i.e. bridge deck) before the demolition and replacement works proves to be a time-efficient strategy if the allocated space in the bridge proximity is large enough to accommodate the erection. Planning of other construction phases (e.g. substructure erection) simultaneously can result in process acceleration.

iii. Careful planning of the demolition and replacement process resulted in full replacement of the TSR Bridge, with length equal to approximately 65 m, within one weekend (100 hours of track outage), including only 10 hours of full traffic closure.

iv. The placement of a pre-erected steel span with length equal to 30 m – 35 m within a time interval of 23 hours is possible, including connection to piers and abutments. The two basic conditions for achieving this rate include the erection of the span in the site proximity and the protection of the existing road surface underneath the span.

v. For a steel rail bridge of 65 m, like is the case for the TSR Bridge, it is possible to perform all preparation works before receiving rail traffic (placement of drainage system, ballast, ties, and tracks) within 23 hours under the condition that waterproofing and painting has been already applied.

Data Availability Statement

Data generated or analyzed during the study are available from the corresponding author upon request.

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